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Stability of Polynuclear Aromatic Compounds Collected from Air on Quartz Fiber Filters and XAD-2 Resin

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16. ABSTRACT

The objective of this project was to investigate the stability of polynuclear aromatic hydrocarbons (PAH) collected from ambient air on quartz fiber filters and XAD-2 resin.

Eight EPA medium volume samplers were set up to collect ambient air for 24 hours at a 6.7 cfm flow rate. Quartz fiber filters and XAD-2 resin were used to collect particulate-bound and vapor-phase PAHs. Prior to sampling, selected perdeuterated PAHs in solution were spiked onto the XAD-2 resin. After collection, two of the filter and XAD-2 resin samples were extracted immediately, and the remaining filters and XAD-2 resin were extracted after 10, 20, and 30 day intervals. The storage temperature was approximately 70°F, and the samples were kept in the dark. Sample extracts were analyzed by electron impact, gas chromatography/mass spectrometry (EI GC/MS).

The results indicated that the levels of perdeuterated and native PAHs on the XAD-2 resin were not adversely influenced by the storage time. The levels of most of the native PAHs, except for cyclopenta[c,d]pyrene, adsorbed on the quartz fiber filters were also not influenced by the storage time. The levels of cyclopenta[c,d]pyrene found in the filters decreased from 1.28 ng/m^3 to 0.79 ng/m^3 after storage for 30 days.

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FOREWORD

Measurement and monitoring research efforts are designated to anticipate environmental problems, to support regulatory actions by developing an in-depth understanding of the nature and processes that impact health and the ecology, to provide innovative means of monitoring compliance with regulations, and to evaluate the effectiveness of health and environmental protection efforts through the monitoring of long-term trends. The Environmental Monitoring Systems Laboratory, Research Triangle Park, North Carolina, has responsibility for assessment of environmental monitoring technology and systems, implementation of agency-wide quality assurance programs for air pollution measurement systems, and supplying technical support to other groups in the Agency including the Office of Air and Radiation, the Office of Toxic Substances, and the Office of Solid Waste.

The determination of human exposure to toxic organic compounds is an area of increasing significance to EPA. The evaluation of XAD-2 resin and quartz fiber filters for collection and quantification of polynuclear aromatic hydrocarbons provides important information that can be applied to the measurement of the extent of human exposure to the polynuclear aromatic compounds.

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ABSTRACT

The objective of this project was to investigate the stability of polynuclear aromatic hydrocarbons (PAH) collected from ambient air on quartz fiber filters and XAD-2 resin.

Eight EPA medium volume samplers were set up to collect ambient air for 24 hours at a 6.7 cfm flow rate. Quartz fiber filters and XAD-2 resin were used to collect particulate-bound and vapor-phase PAHs. Prior to sampling, selected perdeuterated PAHs in solution were spiked onto the XAD-2 resin. After collection, two of the filter and XAD-2 resin samples were extracted immediately, and the remaining filters and XAD-2 resin were extracted after 10, 20, and 30 day intervals. The storage temperature was approximately 70°F, and the samples were kept in the dark. Sample extracts were analyzed by electron impact, gas chromatography/mass spectrometry (EI GC/MS).

The results indicated that the levels of perdeuterated and native PAHs on the XAD-2 resin were not adversely influenced by the storage time. The levels of most the native PAHs, except for cyclopenta[c,d]pyrene, adsorbed on the quartz fiber filters were also not influenced by the storage time. The levels of cyclopenta[c,d]pyrene found in the filters decreased from 1.28 ng/m^3 to 0.79 ng/m^3 after storage for 30 days.

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LIST OF ABBREVIATIONS

BaP	benzo(a)pyrene
EI	electron impact
GC/MS	gas chromatography/mass spectrometry
MID	multiple ion detection
PAH	polynuclear aromatic hydrocarbons
PUF	polyurethane foam

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SECTION 1

INTRODUCTION

Polynuclear aromatic hydrocarbons (PAH) have been extensively studied and have received increased attention in studies of air pollution in recent years because some of these compounds are highly carcinogenic or mutagenic. To understand the extent of human exposure to PAH, reliable sampling and analytical methodology must be established for monitoring the concentrations of these compounds in air. In general, the analytical methodology is well developed, but the sampling procedures can often reduce the validity of analytical results (1). Several studies have shown that the two to four-ring PAH in air may be mainly in the vapor phase and are not retained by filters because of volatilization (2-4). Quartz fiber and glass fiber filters are typically used in sampling air particles. A wide variety of adsorbents such as XAD-2 resin and polyurethane foam (PUF) has been used to sample PAH vapors. However, the overall comparative effectiveness of the collection media and the degree to which quantification of the PAH is affected by sampling, handling and storage are not fully investigated. Recently, Battelle conducted a study (5) to evaluate the stability of PAH collected on polyurethane foam (PUF) as a function of storage conditions. As a follow-up study, the stability of PAH samples collected on quartz fiber filters and XAD-2 resin were evaluated in this program.

The objective of this project was to evaluate quartz fiber filters and XAD-2 resin for collection of particle-bound and vapor-phase PAH in air. In this study the ability of quartz fiber filters and XAD-2 resin to retain PAH were determined by examining the measured PAH concentration as a function of storage time between collection and extraction. In addition, these results were compared with the results of the previous stability study (5) for PUF cartridges to determine whether XAD-2 resin or PUF is a better choice of adsorbent to trap PAH vapors in air.

SECTION 2

CONCLUSIONS

In general, good recoveries of the perdeuterated PAH spiked on the XAD-2 resin were obtained. The recoveries ranged from 73 to 100 percent. In addition, the recoveries of the spiked perdeuterated PAH were not adversely influenced by the 30 days storage time. The levels of all the native PAH adsorbed on XAD-2 resin were also not influenced significantly by the storage time. The results from the previous work, however, showed that the amount of D_{12}-benzo[a]pyrene (BaP) remaining on the PUF cartridge decreased significantly after storage for 30 days under the same storage conditions. Very low recoveries (<10 percent) for D_8-naphthalene were observed in the spiked PUF samples, but in the XAD-2 samples the average recoveries for D_8-naphthalene were 100 percent. These findings demonstrated that XAD-2 resin has better retention efficiency for volatile 2-ring PAH and reactive PAH than the PUF cartridge does. It should be noted that higher molecular weight (m/e $\geq$252) PAH were not detected in the XAD-2 samples, but were found on the filters.

The stabilities of PAH collected on the quartz fiber filters were investigated. The levels of most of the native PAH, except for cyclopenta[c,d]pyrene, on quartz fiber filters were not adversely influenced by the storage time. The levels of cyclopenta[c,d]pyrene decreased from 1.28 ng/m^3 (34.8 ng/mg of particles) to 0.79 ng/m^3 (17.8 ng/mg of particles) after 30 days storage. The loss of cyclopenta[c,d]pyrene was probably due to chemical reaction because the five-member ring is highly susceptible to oxidation. Therefore, if quartz fiber filters are used for ambient or indoor air sampling, minimum sample handling and storage time is recommended to minimize the loss of some reactive PAH.

SECTION 3

RECOMMENDATIONS

In this study, quartz fiber filters were used to collect air particulate matter. However, there are other types of filters which can be considered for collection of particles. Very few studies have been conducted to evaluate filter material for collection of particle-bound PAH. Lee (6) has evaluated various candidate filter materials including glass fiber, quartz fiber, micro-glass fiber with Teflon binder, and Teflon membrane filters. Experiments were performed by spiking solutions of BaP onto filters to determine the recoveries. Spiking of BaP, however, does not represent the native adsorption process of BaP in ambient air sampling. Therefore, we recommend that an evaluation be conducted to compare different types of filters such as quartz fiber, glass fiber, and Teflon-coated filters for collection of PAH in air. Several important characteristics such as flow rate and collection efficiency should be addressed. In addition, studies to determine the effects of storage time on PAH samples collected on different types of filters such as glass fiber and Teflon-coated filters are also recommended.

SECTION 4

EXPERIMENTAL PROCEDURES

SAMPLE COLLECTION

Eight EPA medium volume samplers (modified General Metals PS-1 samplers using General Metals bypass motors in place of the original high-volume blower motors) were employed. Quartz fiber filters followed by XAD-2 resin cartridges in series were used to collect particulate matter and vapors. Samplers were located outside Battelle away from any exhaust openings or heavy traffic. Two sets of four samplers were located in parallel approximately two feet apart. In each set, the samplers were placed about one foot apart. A five foot long exhaust hose was attached to each sampler leading away from the sampler inlet to avoid recirculating the exhaust air to the filter and the XAD-2 cartridge. Prior to sampling, each sampler was calibrated using a Rockwell Model 415 dry gas meter. Adjustments were made with a control and a bypass valve to obtain a flow rate of 6.7 cfm. The readings from the Magnehelic gauge were recorded. Each of the cleaned XAD-2 resin cartridges was spiked with 100 µL of methylene chloride solution containing nominally 30 µg/mL of each of five perdeuterated PAH. Air was then sampled for 24 hours. During the sampling period, the flow rate was checked approximately every four hours. After sampling, a final flow check was conducted on each sampler, and all XAD-2 cartridges as well as filters were wrapped with aluminum foil and transported to the laboratory for analysis. The ambient temperature during the sampling period were ranged from 46°F to 62°F.

PREPARATION OF XAD-2 RESIN:

The pre-cleaned XAD-2 resin was purchased from Supelco Inc. The pre-cleaned XAD-2 resin was extracted with methylene chloride by Soxhlet technique for 16 hours and dried with a ultra pure nitrogen gas stream. The clean XAD-2

resin was placed in the same type glass cartridge which was used for the PUF study (5). An additional nickel wire screen was adapted to the bottom of the glass cartridge to retain the XAD-2 resin. The mesh size of the nickel wire is 200/200 and wire size is 0.0021-0.0022 in. The XAD-2 resin was packed at 2 in. height which allow the maximum sampling flow rate at approximately 7 cfm.

PREPARATION OF STANDARD SOLUTIONS

The stock spiking solution, containing five D_n-PAH at a nominal concentration of 30 µg/mL for each compound, was prepared in methylene chloride and was stored in a 100 mL volumetric flask. The actual concentrations are listed in Table 4.1. Four 1 mL aliquots of the spiking stock solution were

TABLE 4.1. LEVEL OF DEUTERATED PAH IN THE STOCK SPIKING SOLUTION

Compound	Concentration of Standard, µg/mL
D_8-naphthalene	36.7
D_{10}-phenanthrene	34.0
D_{10}-pyrene	32.0
D_{12}-chrysene	37.3
D_{12}-benzo[a]pyrene	34.3

transferred into four 2-mL GC vials for field use. Prior to sampling, exactly 100 µL of the spiking solution was withdrawn into a 100 µL syringe, and the spike was injected approximately one inch deep into the cleaned XAD-2 resin.

Another stock solution containing selected native PAH was prepared at a nominal concentration of 100 µg/mL per compound. The actual concentrations in this solution are listed in Table 4.2. This solution was used to prepare 0.3 µg/mL, 1 µg/mL and 5 µg/mL standard solutions. These solutions also

contained the spiked D_n-PAH at these same concentration levels and the internal standard, 9-phenylanthracene, at a constant concentration of 1 µg/mL.

TABLE 4.2. LEVEL OF NON-DEUTERATED PAH IN THE STOCK STANDARD SOLUTION

Compound	Concentration of Standard, µg/mL
Naphthalene	100
Phenanthrene	106
Anthracene	100
Fluoranthene	99
Pyrene	100
Cyclopenta[c,d]pyrene	100
Benz[a]anthracene	100
Chrysene	100
Benzo[e]pyrene	80
Benzo[a]pyrene	100
Benzo[g,h,i]perylene	100
Coronene	50

SAMPLE PREPARATION FOR THE STABILITY STUDY

Eight filter and XAD-2 samples were collected for the stability study. The filter and XAD-2 samples were individually wrapped with aluminum foil and stored in the dark at room temperature (~70°C). These samples were stored in the dark for 0- ten-, twenty-, or thirty-day intervals before extraction. Two of the filters and two of XAD-2 cartridges were extracted as duplicate pairs, after each of the four storage intervals. The filters and the XAD-2 cartridges were Soxhlet extracted with 400 mL and 800 mL of methylene chloride respectively. The extractions were carried out for 16 hours or until the solvents in the extractors were clear. After extraction, the extracts were concentrated to 1 mL by Kuderna-Danish evaporation. No further sample clean-up procedures were applied to the concentrated extracts. The internal standard, 9-phenylanthracene, was added to all sample extracts at a level of 1 µg/mL prior to GC/MS analysis.

GAS CHROMATOGRAPHY/MASS SPECTROMETRY (GC/MS)

Electron impact gas chromatography/mass spectrometry (EI GC/MS) in the multiple ion detection (MID) mode was employed to determine the native PAH and the spiked D_n-PAH. The instrumentation conditions that were used are summarized in Table 4.3. A Finnigan Model 4500 quadrupole mass spectrometer equipped with an EI/CI source was used for the analyses. The molecular ion of each target compound was monitored. The ion source temperature was held at 180°C and the electron multiplier was operated at a gain of approximately 10^5.

An Ultra #2 fused silica capillary column (50m x 0.31 mm I.D., 0.17 µm film thickness, Hewlett-Packard Co.) with methane carrier gas was used for analyte separation. The GC column interfaced directly to the MS ion source. The GC column temperature was held at 45°C for 1 min, programmed rapidly to 100°C in 5 min, and then programmed from 100°C to 320°C at 8°C/min.

The standard solutions and sample extracts were analyzed by EI GC/MS. Identifications of the PAH compounds in the sample extracts were based on the correct mass ion and the correct retention time relative to the internal standard as determined from the standard analyses. The standard analyses were also used to calculate the response factor for each compound relative to the internal standard. The following equation was used for quantification:

$$C_x = \frac{A_x \times C_{is} \times FV}{A_{is} \times R_f}$$

where:

C_x = Total amount of a target compound in the extract, µg
A_x = Molecular ion integration area of a target compound
C_{is} = Concentration of the internal standard, µg/mL
A_{is} = Molecular ion integration area of the internal standard
R_f = Response factor of a target compound
FV = Final volume of the extract, mL

TABLE 4.3. GC AND MS OPERATING CONDITIONS

Chromatography	
Column:	HP Ultra #2 crosslinked 5% phenyl methyl silicone 50m x 0.31 mm, 0.17 µm film thickness
Carrier gas:	CH_4
Injection volume:	2 µL
Injection mode:	Splitless
Temperature Program	
Initial column temperature:	45°C
Initial hold time:	1 min
Program:	45°C to 100°C in 5 min, then 100°C to 320°C at 8°C/min
Final hold time:	15 min
Mass Spectrometer	
Ionization:	Electron impact at 70 eV
Emission current:	0.3 m amp
Preamplifier:	10^{-8} amp/volt
Detection mode:	Multiple ion detection

SECTION 5

RESULTS AND DISCUSSION

The stability study was conducted to determine whether a significant loss of PAH captured by XAD-2 resin and quartz fiber filters occurred during the storage period. The particulate weights for all the filter samples are summarized in Table 5.1. The recovery data of the perdeuterated PAH from the XAD-2 samples are given in Table 5.2. Concentrations of native PAH found in the XAD-2 samples are calculated as ng/m^3 and are summarized in Table 5.3. Concentrations of native PAH found in the filter samples are calculated as ng/m^3 as well as ng/mg of particulate and are summarized in Tables 5.4 and 5.5, respectively.

Recoveries of the perdeuterated PAH for the XAD-2 samples ranged from 71 percent for D_{12}-benzo[a]pyrene to 103 percent for D_8-naphthalene. In general, good recoveries were obtained for all the spiked PAH. In addition, the storage time did not appear to have adverse effects on the recoveries of either the spiked PAH or the native PAH. The sampling conditions of this study were comparable to those used in the previous study (5). But the previous study gave low recoveries for D_8-naphthalene from the spiked PUF sample, which decreased from 1.2 percent to 0.6 percent. The recoveries of D_{12}-BaP also decreased from 96 percent to 30 percent after 30 days storage on PUF. These findings indicate that XAD-2 resin has better retention efficiency for the volatile and reactive PAH than the PUF cartridge does. Only volatile and semi-volatile PAH were found in the XAD-2 resin. Higher molecular weight PAH ($m/e \geq 252$), such as BaP and benzo[g,h,i]perylene, were not detected in the XAD-2 resin. The concentrations of the native PAH from the XAD-2 samples were not decreased significantly after 30 days storage.

TABLE 5.1. PARTICULATE WEIGHT OF FILTER SAMPLES

Sample Code	Total Particulate Weight,(a) mg
A	9.6
B	9.8
C	9.4
D	9.6
E	10.3
F	10.7
G	11.0
H	11.5

(a) The average particulate weight of eight filters is 10.1 $\pm$ 0.9 (9%) mg.

The distribution of PAH between the filters and the XAD-2 resin agreed with the volatilities of the compounds, and the majority of the volatile PAH ($\leq$4 rings) were captured on the XAD-2 resin. The non-volatile PAH, such as BaP and coronene, were captured mainly on the quartz fiber filters. The storage time did not significantly affect the levels of most of the PAH on quartz fiber filters, except for cyclopenta[c,d]pyrene. The concentration of cyclopenta[c,d]pyrene decreased from 1.28 ng/m^3 (34.8 ng/mg of particles) to 0.79 ng/m^3 (17.8 ng/mg of particles) after 30 days storage and is shown in Figure 1. The loss of cyclopenta[c,d]pyrene may be due to chemical reaction (e.g. oxidation), because the five member ring is highly susceptible to oxidation.

TABLE 5.2. RECOVERIES OF PAH FROM XAD-2 RESIN SPIKED PRIOR TO SAMPLING AS A FUNCTION OF STORAGE TIME

Compound Name	Percent Recovery Storage Time Between Sampling and Extraction, Days 1	10	20	30
D_8-Naphthalene	100 (97-110)[a]	110 (110-110)	96 (90-100)	96 (83-110)
D_{10}-Phenanthrene	84 (82-85)	85 (33-87)	92 (90-93)	82 (80-84)
D_{10}-Pyrene	88 (87-89)	93 (91-94)	99 (96-100)	90 (88-92)
D_{12}-Chrysene	82 (79-84)	84 (82-85)	90 (89-91)	79 (78-79)
D_{12}-Benzo[a]pyrene	73 (71-74)	72 (71-73)	77 (74-80)	71 (70-71)

(a) The first number given is the mean of the duplicate samples; the second and third numbers are the range of the duplicate samples.

TABLE 5.3. LEVELS OF NATIVE PAH FOUND IN XAD-2 RESIN AS A FUNCTION OF STORAGE TIME

Compound Name	Concentration, ng/m^3[a] Storage Time Between Sampling and Extraction, Days 1	10	20	30
Naphthalene	80.0 (73.7-86.3)[b]	78.5 (78.1-78.8)	75.5 (74.5-76.4)	76.3 (75.7-76.8)
Phenanthrene	43.3 (40.1-46.4)	43.9 (42.0-45.8)	41.8 (38.4-45.1)	38.4 (36.3-40.4)
Anthracene	1.31 (1.28-1.33)	1.52 (1.43-1.60)	1.47 (1.34-1.59)	1.46 (1.32-1.60)
Fluoranthene	7.12 (6.95-7.28)	7.35 (7.22-7.48)	7.71 (6.96-8.45)	6.67 (6.41-6.93)
Pyrene	3.87 (3.91-3.82)	4.01 (3.98-4.03)	4.39 (3.99-4.79)	3.77 (3.47-4.06)
Cyclopenta[c,d]pyrene	0.11 (0.11-0.11)	0.07 (0.07-0.07)	0.06 (0.05-0.07)	0.12 (0.14-0.09)
Benz[a]anthracene	0.17 (0.17-0.17)	0.22 (0.22-0.22)	0.20 (0.17-0.22)	0.25 (0.24-0.26)
Chrysene	0.30 (0.30-0.29)	0.31 (0.30-0.32)	0.36 (0.32-0.40)	0.38 (0.37-0.39)
Benzo[e]pyrene	--[c]	--	--	--
Benzo[a]pyrene	--	--	--	--
Benzo[g,h,i]perylene	--	--	--	--
Coronene	--	--	--	--

(a) Expressed as ng of PAH per cubic meter of air sampled.
(b) The first number given is the mean of the duplicate samples; the second and third numbers are the range of the duplicate samples.
(c) Not Detected.

TABLE 5.4. LEVELS OF NATIVE PAH FOUND IN QUARTZ FIBER FILTERS AS A FUNCTION OF STORAGE TIME

Compound Name	Concentration, ng/m^3(a) Storage Time Between Sampling and Extraction, Days 1	10	20	30
Naphthalene	0.20 (0.19-0.21)(b)	0.17 (0.15-0.19)	0.17 (0.19-0.15)	0.20 (0.19-0.21)
Phenanthrene	1.64 (1.57-1.70)	1.83 (1.63-2.02)	1.87 (1.87-1.87)	2.56 (2.31-2.82)
Anthracene	0.20 (0.19-0.21)	0.20 (0.18-0.22)	0.21 (0.21-0.21)	0.26 (0.25-0.27)
Fluoranthene	1.90 (1.85-1.95)	1.74 (1.64-1.83)	1.84 (1.81-1.87)	2.19 (2.16-2.22)
Pyrene	1.75 (1.18-1.31)	1.20 (1.12-1.27)	1.28 (1.25-1.31)	1.47 (1.41-1.52)
Cyclopenta[c,d]pyrene	1.28 (1.19-1.37)	0.99 (0.97-1.01)	0.82 (0.81-0.83)	0.79 (0.79-0.79)
Benz[a]anthracene	1.01 (0.96-1.06)	1.04 (1.01-1.06)	1.06 (1.03-1.08)	1.14 (1.10-1.17)
Chrysene	1.68 (1.65-1.70)	1.70 (1.65-1.75)	1.76 (1.72-1.80)	1.91 (1.90-1.92)
Benzo[e]pyrene	0.81 (0.79-0.83)	0.87 (0.84-0.89)	0.89 (0.88-0.90)	0.92 (0.91-0.93)
Benzo[a]pyrene	0.70 (0.65-0.74)	0.74 (0.72-0.76)	0.75 (0.74-0.75)	0.74 (0.72-0.76)
Benzo[g,h,i]perylene	1.19 (1.16-1.22)	1.28 (1.24-1.31)	1.37 (1.24-1.50)	1.28 (1.24-1.31)
Coronene	1.95 (1.72-2.17)	2.01 (1.82-2.09)	2.26 (2.76-1.76)	1.88 (1.80-1.96)

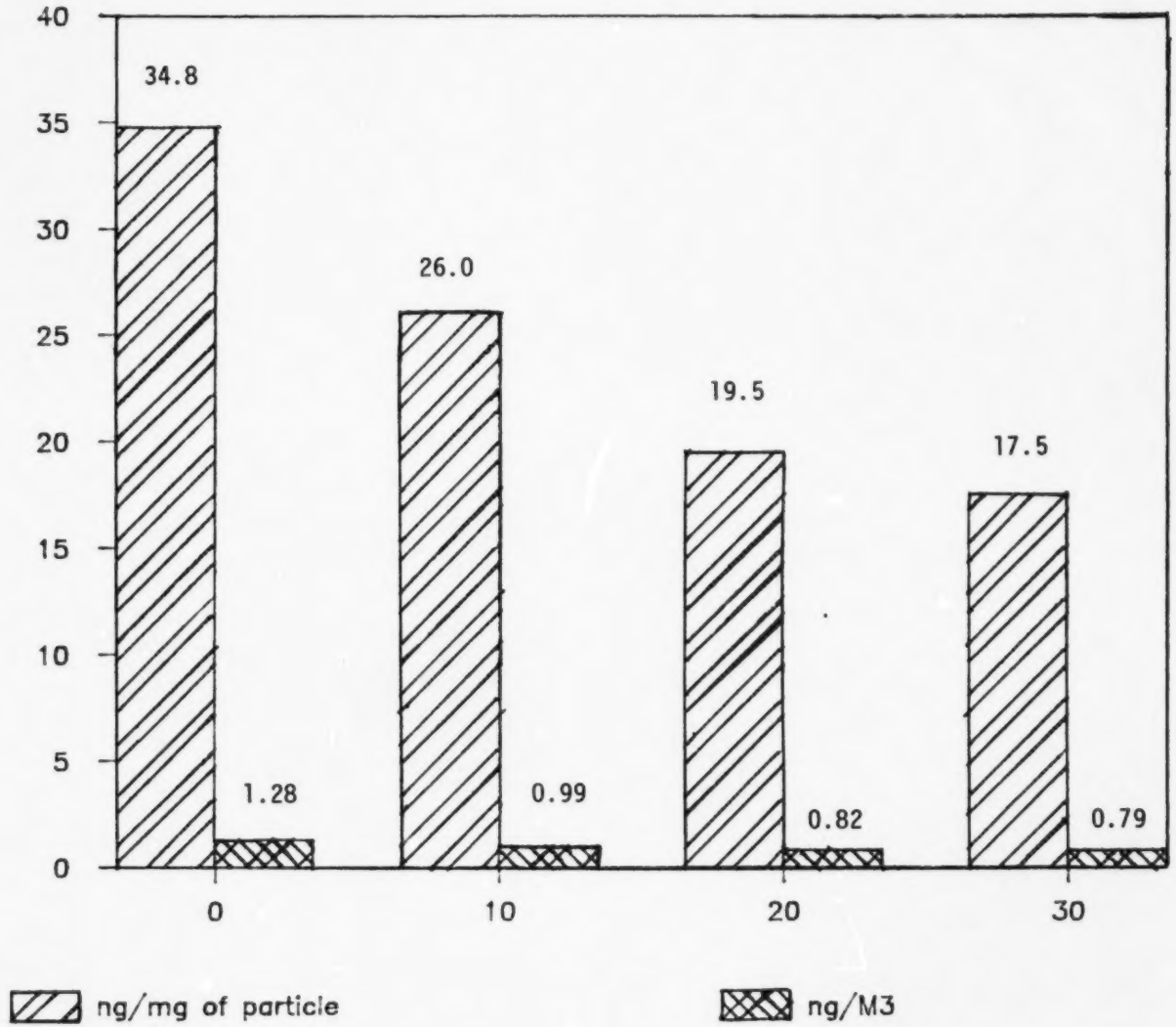
(a) Expressed as ng of PAH per cubic meter of air sampled.
(b) The first number given is the mean of the duplicate samples; the second and third numbers are the range of the duplicate samples.

TABLE 5.5. LEVELS OF NATIVE PAH FOUND IN QUARTZ FIBER FILTERS AS A FUNCTION OF STORAGE TIME

Compound Name	Concentration, ng/mg of Particles[a] Storage Time Between Sampling and Extraction, Days 1	10	20	30
Naphthalene	5.43 (5.32-5.54)[b]	4.50 (3.95-5.04)	3.99 (3.60-4.37)	4.37 (4.25-4.49)
Phenanthrene	44.4 (40.7-48.1)	47.8 (43.2-52.4)	44.5 (43.6-45.3)	57.1 (50.1-64.0)
Anthracene	5.31 (5.30-5.32)	5.26 (4.73-5.79)	4.98 (4.96-4.99)	5.74 (5.41-6.06)
Fluoranthene	51.6 (50.7-52.4)	45.6 (43.5-47.6)	43.6 (43.5-43.7)	48.7 (46.9-50.4)
Pyrene	33.8 (33.5-34.1)	31.4 (29.8-32.9)	30.4 (30.3-30.4)	32.5 (30.5-34.5)
Cyclopenta[c,d]pyrene	34.8 (33.8-35.7)	26.0 (25.7-26.3)	19.5 (19.4-19.6)	17.5 (17.1-17.9)
Benz[a]anthracene	27.4 (27.2-27.6)	27.2 (26.8-27.6)	24.9 (24.6-25.2)	25.1 (24.9-25.3)
Chrysene	45.5 (44.2-46.8)	44.7 (43.8-45.5)	41.8 (41.6-42.0)	42.5 (41.3-43.6)
Benzo[e]pyrene	22.0 (21.6-22.3)	22.8 (22.4-23.2)	21.1 (20.5-21.6)	20.4 (20.1-20.7)
Benzo[a]pyrene	18.8 (18.4-19.3)	19.5 (19.1-19.8)	17.8 (17.3-18.2)	16.4 (16.3-16.5)
Benzo[g,h,i]perylene	32.2 (31.7-32.7)	33.5 (33.0-34.0)	32.7 (29.0-36.4)	28.3 (26.9-29.7)
Coronene	52.5 (48.7-56.3)	52.6 (51.0-54.2)	54.0 (40.1-66.9)	41.8 (39.0-44.5)

(a) Expressed as ng of PAH per mg of particulate matter sampled.
(b) The first number given is the mean of the duplicate samples; the second and third numbers are the range of the duplicate samples.

FIGURE 5.1. LEVELS OF CYCLOPENTA[c,d]PYRENE IN QUARTZ FIBER FILTERS AS A FUNCTION OF STORAGE TIME.



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